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NEUTRON SPECTRA IN THE SIDE-SHIELDING
OF A LARGE PARTICLE ACCELERATOR

January 1971

Health and Safety Laboratory
New York Operations Office (AEC)
New York, New York

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NEUTRON SPECTRA IN THE SIDE-SHIELDING OF A
LARGE PARTICLE ACCELERATOR

Keran O'Brien

January 1971

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Health and Safety Laboratory
U. S. Atomic Energy Commission
New York, N. Y. 10014

ABSTRACT

Neutron spectra covering the range from thermal to 500 MeV in the side-shielding of high energy electron and proton accelerators have been calculated. Shield thicknesses vary from 100 to 2000 g/cm² of earth and iron. The results should be applicable to particle accelerators with energies greater than 0.8 GeV under conditions of uniform beam loss.

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INTRODUCTION

High-energy electrons or protons lost during acceleration produce nuclear reactions or "stars" while coming to rest. These stars emit neutrons which must be shielded against. In this paper are tables of neutron spectra at various depths in earth barriers containing 16% water by weight, or 32.83% H-atoms per atom, and in iron. The barriers range from 100 to 2000 g/cm² in depth, and the spectra cover the range from thermal to 500 MeV. The energy spectrum of neutrons from a nuclear star is assumed to be independent of the energy and type of the initiating hadron or photon.

This report should be considered a companion document to Refs. ⁽¹⁾ and ⁽²⁾ as an aid in the design of shielding at the National Accelerator Laboratory⁽³⁾.

DETAILS OF THE CALCULATION

A uniform beam spill of high-energy particles of greater than 0.8 GeV is assumed to occur such that a uniform source of one nuclear star per second per centimeter of accelerator structure is formed. The resulting neutron flux per second per steradian per MeV incident on the shield wall is calculated from a formula given by Ranft⁽⁴⁾. The neutron transport through the shield is performed by the method of spherical harmonics⁽⁵⁾.

The surrounding shield is postulated to be a single medium of earth or iron, a cylindrical shell of uniform thickness, with the accelerator structure in its center.

RESULTS

The calculated neutron spectra are given in Table 1 through 9. These data are useful in estimating dose and dose equivalent rates outside shields and in radioactivation calculations. The tabulated values are per ($\text{cm}^2 \text{ MeV s}$) for a unit cylinder, and to be converted to the flux at a distance r cm from the center of the accelerator structure should be divided by $2\pi r$. In addition, the number of nuclear stars produced when an energetic hadron is introduced in matter is

$$\nu_* = 2E_i \quad (1)$$

where E_i is the kinetic energy of the hadron in GeV. When an energetic electron or photon is introduced in matter the number of nuclear stars is

$$\nu_* = 2.34 \times 10^{-3} (\bar{X}_0/12.8) E_i \log_{10} (5E_i) \quad (2)$$

where $\bar{X}_0$ is the radiation length in g/cm^2 (1,2,6).

It follows then that if φ_{tx} is the tabulated neutron flux per ($\text{cm}^2 \text{ MeV s}$) at a depth of $x \text{ g/cm}^2$ in a specific shield in one of the following tables, and this depth is at a distance r cm from the center of the accelerating structure along which a uniform spill of E_i GeV electrons or protons occurs, that the true flux is

$$\varphi = \varphi_{tx} \frac{\nu_*}{2\pi r} \frac{dJ}{dL} \quad (3)$$

where dJ/dL is the number of protons or electrons spilled per centimeter per second.

For proton machines, this reduces to

$$\varphi = \frac{0.3183}{r} \varphi_{tx} E_i \left(\frac{dJ}{dL} \right) \quad (4)$$

and for electron machines

$$\varphi = \frac{3.72 \times 10^{-4}}{5} \left(\frac{\bar{X}_0}{12.8} \right) \varphi_{tx} E_i \log_{10} (5E_i) \left(\frac{dJ}{dL} \right) \quad (5)$$

where $\bar{X}_0$ is the radiation length of the accelerating structure.

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USAEC Report CONF-691101, p. 253-301 (1969)

TABLE 1

BARRIER IS 100 g/cm², 32.83% HDepth in Barrier is 100 g/cm²

<u>Energy</u> (MeV)	<u>Flux</u> (cm ² s) ⁻¹
5.01E+02	1.1597E-04
3.98E+02	2.0120E-04
3.16E+02	3.0305E-04
2.51E+02	4.5357E-04
2.00E+02	6.5172E-04
1.58E+02	8.8676E-04
1.26E+02	1.0885E-03
1.00E+02	1.3062E-03
7.94E+01	1.4622E-03
6.31E+01	1.6064E-03
5.01E+01	1.6800E-03
3.98E+01	1.8072E-03
3.16E+01	1.9626E-03
2.51E+01	2.0664E-03
2.00E+01	1.8396E-03
1.58E+01	2.0809E-03
1.26E+01	2.3861E-03
1.00E+01	2.9289E-03
7.94E+00	3.8663E-03
6.31E+00	4.9854E-03
5.01E+00	6.7972E-03
3.98E+00	8.8260E-03
3.16E+00	1.1425E-02
2.51E+00	1.4470E-02
2.00E+00	1.7445E-02
1.58E+00	2.0068E-02
1.26E+00	2.1908E-02
1.00E+00	2.3571E-02
7.94E-01	2.5576E-02
6.31E-01	2.7882E-02
5.01E-01	2.9182E-02
3.98E-01	2.8858E-02
3.16E-01	3.4491E-02
2.51E-01	3.5762E-02
2.00E-01	3.5902E-02

TABLE 1

BARRIER IS 100 g/cm², 32.83% H (CONT'D)Depth in Barrier is 100 g/cm²

$\frac{\text{Energy}}{(\text{MeV})}$	$\frac{\text{Flux}}{(\text{cm}^2 \text{ s})^{-1}}$
1.58E-01	3.5762E-02
1.26E-01	4.0731E-02
1.00E-01	4.7066E-02
7.94E-02	3.8424E-02
6.31E-02	8.1664E-02
5.01E-02	7.9523E-02
3.98E-02	7.9457E-02
3.16E-02	5.1807E-02
2.51E-02	1.5694E-01
2.00E-02	1.6066E-01
1.58E-02	1.8704E-01
1.26E-02	2.2364E-01
1.00E-02	2.6788E-01
7.94E-03	3.2274E-01
6.31E-03	3.8703E-01
5.01E-03	4.7626E-01
3.98E-03	6.0641E-01
3.16E-03	7.5997E-01
2.51E-03	9.5298E-01
2.00E-03	1.1922E+00
1.58E-03	1.5052E+00
1.26E-03	1.8836E+00
1.00E-03	2.3693E+00
7.94E-04	2.9799E+00
6.31E-04	3.7454E+00
5.01E-04	4.7128E+00
3.98E-04	5.9277E+00
3.16E-04	7.4606E+00
2.51E-04	9.3868E+00
2.00E-04	1.1774E+01
1.58E-04	1.4896E+01
1.26E-04	1.8670E+01
1.00E-04	2.3512E+01
7.94E-05	2.9596E+01
6.31E-05	3.7222E+01

TABLE 1

BARRIER IS 100 g/cm², 32.83% H (CONT'D)Depth in Barrier is 100 g/cm²

<u>Energy</u> (MeV)	<u>Flux</u> (cm ² s) ⁻¹
5.01E-05	4.6854E+01
3.98E-05	5.8943E+01
3.16E-05	7.4190E+01
2.51E-05	9.3334E+01
2.00E-05	1.1704E+02
1.58E-05	1.4802E+02
1.26E-05	1.8543E+02
1.00E-05	2.3338E+02
7.94E-06	2.9357E+02
6.31E-06	3.6889E+02
5.01E-06	4.6389E+02
3.98E-06	5.8293E+02
3.16E-06	7.3277E+02
2.51E-06	9.2053E+02
2.00E-06	1.1524E+03
1.58E-06	1.4548E+03
1.26E-06	1.8187E+03
1.00E-06	2.2837E+03
7.94E-07	2.8650E+03
6.31E-07	3.5895E+03
2.51E-08	1.5013E+05

TABLE 2

BARRIER IS 1000 g/cm², 32.83% HDepth in Barrier is 100 g/cm²

<u>Energy</u> (MeV)	<u>Flux</u> (cm ² s) ⁻¹
5.01E+02	1.0985E-04
3.98E+02	1.9502E-04
3.16E+02	2.9988E-04
2.51E+02	4.5597E-04
2.00E+02	6.6601E-04
1.58E+02	9.2328E-04
1.26E+02	1.1566E-04
1.00E+02	1.4158E-03
7.94E+01	1.6404E-03
6.31E+01	1.8823E-03
5.01E+01	2.0596E-03
3.98E+01	2.3218E-03
3.16E+01	2.6433E-03
2.51E+01	2.9190E-03
2.00E+01	2.7246E-03
1.58E+01	3.1276E-03
1.26E+01	3.7087E-03
1.00E+01	4.7390E-03
7.94E+00	6.5970E-03
6.31E+00	9.1870E-03
5.01E+00	1.3245E-02
3.98E+00	1.8290E-02
3.16E+00	2.5588E-02
2.51E+00	3.4785E-02
2.00E+00	4.4855E-02
1.58E+00	5.4231E-02
1.26E+00	6.1823E-02
1.00E+00	6.9885E-02
7.94E-01	7.9194E-02
6.31E-01	8.8843E-02
5.01E-01	9.6576E-02
3.98E-01	1.0197E-01
3.16E-01	1.2168E-01
2.51E-01	1.2957E-01
2.00E-01	1.3816E-01
1.58E-01	1.4956E-01

TABLE 2

BARRIER IS 1000 g/cm², 32.83% H (CONT'D)Depth in Barrier is 100 g/cm²

<u>Energy</u> (MeV)	<u>Flux</u> (cm ² s) ⁻¹
1.26E-01	1.7672E-01
1.00E-01	2.0638E-01
7.94E-02	1.9612E-01
6.31E-02	3.3745E-01
5.01E-02	3.1876E-01
3.98E-02	3.4689E-01
3.16E-02	3.0444E-01
2.51E-02	6.8980E-01
2.00E-02	6.4632E-01
1.58E-02	7.5431E-01
1.26E-02	9.1064E-01
1.00E-02	1.1033E+00
7.94E-03	1.3424E+00
6.31E-03	1.6311E+00
5.01E-03	2.0072E+00
3.98E-03	2.5557E+00
3.16E-03	3.2029E+00
2.51E-03	4.0163E+00
2.00E-03	5.0246E+00
1.58E-03	6.3435E+00
1.26E-03	7.9384E+00
1.00E-03	9.9854E+00
7.94E-04	1.2559E+01
6.31E-04	1.5785E+01
5.01E-04	1.9862E+01
3.98E-04	2.4982E+01
3.16E-04	3.1443E+01
2.51E-04	3.9561E+01
2.00E-04	4.9621E+01
1.58E-04	6.2778E+01
1.26E-04	7.8683E+01
1.00E-04	9.9090E+01
7.94E-05	1.2473E+02
6.31E-05	1.5687E+02
5.01E-05	1.9746E+02
3.98E-05	2.4812E+02
3.16E-05	3.1267E+02
2.51E-05	3.9335E+02

TABLE 2

BARRIER IS 1000 g/cm², 32.83% H (CONT'D)Depth in Barrier is 100 g/cm²

<u>Energy</u> (MeV)	<u>Flux</u> (cm ² s) ⁻¹
2.00E-05	4.9326E+02
1.58E-05	6.2383E+02
1.26E-05	7.8149E+02
1.00E-05	9.8358E+02
7.94E-06	1.2372E+03
6.31E-06	1.5547E+03
5.01E-06	1.9551E+03
3.98E-06	2.4568E+03
3.16E-06	3.0883E+03
2.51E-06	3.8796E+03
2.00E-06	4.8570E+03
1.58E-06	6.1312E+03
1.26E-06	7.6648E+03
1.00E-06	9.6245E+03
7.94E-07	1.2075E+04
6.31E-07	1.5128E+04
2.51E-08	4.8275E+05

TABLE 3

BARRIER IS 1000 g/cm², 32.83% HDepth in Barrier is 200 g/cm²

<u>Energy</u> (MeV)	<u>Flux</u> (cm ² s) ⁻¹
5.01E+02	1.9025E-05
3.98E+02	4.2849E-05
3.16E+02	7.6814E-05
2.51E+02	1.3288E-04
2.00E+02	2.1436E-04
1.58E+02	3.1850E-04
1.26E+02	4.1152E-04
1.00E+02	5.1375E-04
7.94E+01	5.8907E-04
6.31E+01	6.6679E-04
5.01E+01	7.1553E-04
3.98E+01	8.0005E-04
3.16E+01	9.0707E-04
2.51E+01	9.9547E-04
2.00E+01	9.1612E-04
1.58E+01	1.0446E-03
1.26E+01	1.2276E-03
1.00E+01	1.5655E-03
7.94E+00	2.1862E-03
6.31E+00	3.0495E-03
5.01E+00	4.4041E-03
3.98E+00	6.0879E-03
3.16E+00	8.5230E-03
2.51E+00	1.1593E-02
2.00E+00	1.4955E-02
1.58E+00	1.8076E-02
1.26E+00	2.0607E-02
1.00E+00	2.3296E-02
7.94E-01	2.6399E-02
6.31E-01	2.9616E-02
5.01E-01	3.2194E-02
3.98E-01	3.3992E-02
3.16E-01	4.0563E-02
2.51E-01	4.3192E-02
2.00E-01	4.6057E-02
1.58E-01	4.9856E-02

TABLE 3

BARRIER IS 1000 g/cm², 32.83% H (CONT'D)Depth in Barrier is 200 g/cm²

<u>Energy</u> (MeV)	<u>Flux</u> (cm ² s) ⁻¹
1.26E-01	5.8908E-02
1.00E-01	6.8797E-02
7.94E-02	6.5377E-02
6.31E-02	1.1249E-01
5.01E-02	1.0626E-01
3.98E-02	1.1564E-01
3.16E-02	1.0149E-01
2.51E-02	2.2995E-01
2.00E-02	2.1546E-01
1.58E-02	2.5146E-01
1.26E-02	3.0357E-01
1.00E-02	3.6780E-01
7.94E-03	4.4752E-01
6.31E-03	5.4377E-01
5.01E-03	6.6914E-01
3.98E-03	8.5200E-01
3.16E-03	1.0678E+00
2.51E-03	1.3389E+00
2.00E-03	1.6751E+00
1.58E-03	2.1148E+00
1.26E-03	2.6464E+00
1.00E-03	3.3289E+00
7.94E-04	4.1867E+00
6.31E-04	5.2623E+00
5.01E-04	6.6214E+00
3.98E-04	8.3283E+00
3.16E-04	1.0182E+01
2.51E-04	1.3188E+01
2.00E-04	1.6542E+01
1.58E-04	2.0929E+01
1.26E-04	2.6231E+01
1.00E-04	3.3034E+01
7.94E-05	4.1583E+01
6.31E-05	5.2297E+01
5.01E-05	6.5829E+01

TABLE 3

BARRIER. IS 1000 g/cm², 32.83% H (CONT'D)Depth in Barrier is 200 g/cm²

<u>Energy</u> (MeV)	<u>Flux</u> (cm ² s) ⁻¹
3.98E-05	8.2815E+01
3.16E-05	1.0424E+02
2.51E-05	1.3113E+02
2.00E-05	1.6444E+02
1.58E-05	2.0797E+02
1.26E-05	2.6053E+02
1.00E-05	3.2790E+02
7.94E-06	4.1246E+02
6.31E-06	5.1829E+02
5.01E-06	6.5176E+02
3.98E-06	8.1901E+02
3.16E-06	1.0295E+03
2.51E-06	1.2933E+03
2.00E-06	1.6192E+03
1.58E-06	2.0440E+03
1.26E-06	2.5552E+03
1.00E-06	3.2085E+03
7.94E-07	4.0254E+03
6.31E-07	5.0433E+03
2.51E-08	1.8133E+05

TABLE 4

BARRIER IS 1000 g/cm², 32.83% HDepth in Barrier is 500 g/cm²

$\frac{\text{Energy}}{(\text{MeV})}$	$\frac{\text{Flux}}{(\text{cm}^2 \text{ s})^{-1}}$
5.01E+02	5.7341E-07
3.98E+02	1.6295E-06
3.16E+02	3.3196E-06
2.51E+02	6.5770E-06
2.00E+02	1.1707E-05
1.58E+02	1.8334E-05
1.26E+02	2.3717E-05
1.00E+02	2.9567E-05
7.94E+01	3.2733E-05
6.31E+01	3.6204E-05
5.01E+01	3.8230E-05
3.98E+01	4.2458E-05
3.16E+01	4.7953E-05
2.51E+01	5.2906E-05
2.00E+01	4.8413E-05
1.58E+01	5.5108E-05
1.26E+01	6.4710E-05
1.00E+01	8.2665E-05
7.94E+00	1.1571E-04
6.31E+00	1.6176E-04
5.01E+00	2.3381E-04
3.98E+00	3.2337E-04
3.16E+00	4.5279E-04
2.51E+00	6.1584E-04
2.00E+00	7.9435E-04
1.58E+00	9.5866E-04
1.26E+00	1.0925E-03
1.00E+00	1.2349E-03
7.94E-01	1.3994E-03
6.31E-01	1.5698E-03
5.01E-01	1.7064E-03
3.98E-01	1.8019E-03
3.16E-01	2.1499E-03
2.51E-01	2.2892E-03
2.00E-01	2.4410E-03
1.58E-01	2.6425E-03

TABLE 4

BARRIER IS 1000 g/cm², 32.83% H (CONT'D)Depth in Barrier is 500 g/cm²

$\frac{\text{Energy}}{(\text{MeV})}$	$\frac{\text{Flux}}{(\text{cm}^2 \text{ s})^{-1}}$
1.26E-01	3.1222E-03
1.00E-01	3.6462E-03
7.94E-02	3.4652E-03
6.31E-02	5.9607E-03
5.01E-02	5.6301E-03
3.98E-02	6.1271E-03
3.16E-02	5.3781E-03
2.51E-02	1.2183E-02
2.00E-02	1.1413E-02
1.58E-02	1.3320E-02
1.26E-02	1.6079E-02
1.00E-02	1.9480E-02
7.94E-03	2.3700E-02
6.31E-03	2.8796E-02
5.01E-03	3.5435E-02
3.98E-03	4.5118E-02
3.16E-03	5.6544E-02
2.51E-03	7.0904E-02
2.00E-03	8.8705E-02
1.58E-03	1.1199E-01
1.26E-03	1.4014E-01
1.00E-03	1.7628E-01
7.94E-04	2.2171E-01
6.31E-04	2.7867E-01
5.01E-04	3.5064E-01
3.98E-04	4.4103E-01
3.16E-04	5.5509E-01
2.51E-04	6.9841E-01
2.00E-04	8.7602E-01
1.58E-04	1.1083E+00
1.26E-04	1.3891E+00
1.00E-04	1.7493E+00
7.94E-05	2.2021E+00
6.31E-05	2.7694E+00
5.01E-05	3.4860E+00
3.98E-05	4.3855E+00

TABLE 4

BARRIER IS 1000 g/cm², 32.83% H (CONT'D)Depth in Barrier is 500 g/cm²

$\frac{\text{Energy}}{(\text{MeV})}$	$\frac{\text{Flux}}{(\text{cm}^2 \text{ s})^{-1}}$
3.16E-05	5.5190E+00
2.51E-05	6.9114E+00
2.00E-05	8.7081E+00
1.58E-05	1.1013E+01
1.26E-05	1.3796E+01
1.00E-05	1.7364E+01
7.94E-06	2.1842E+01
6.31E-06	2.7446E+01
5.01E-06	3.4515E+01
3.98E-06	4.3372E+01
3.16E-06	5.4520E+01
2.51E-06	6.8190E+01
2.00E-06	8.5745E+01
1.58E-06	1.0824E+02
1.26E-06	1.3531E+02
1.00E-06	1.6991E+02
7.94E-07	2.1317E+02
6.31E-07	2.6707E+02
2.51E-08	9.4718E+03

TABLE 5

BARRIER IS 1000 g/cm², 32.83% HDepth in Barrier is 1000 g/cm²

<u>Energy</u> (MeV)	<u>Flux</u> (cm ² s) ⁻¹
5.01E+02	2.4140E-09
3.98E+02	8.6975E-09
3.16E+02	1.9970E-08
2.51E+02	4.5477E-08
2.00E+02	8.9353E-08
1.58E+02	1.4652E-07
1.26E+02	1.8920E-07
1.00E+02	2.3393E-07
7.94E+01	2.5007E-07
6.31E+01	2.6389E-07
5.01E+01	2.6462E-07
3.98E+01	2.7898E-07
3.16E+01	2.9893E-07
2.51E+01	3.1004E-07
2.00E+01	2.7077E-07
1.58E+01	3.0132E-07
1.26E+01	3.3869E-07
1.00E+01	4.1252E-07
7.94E+00	5.4526E-07
6.31E+00	7.0387E-07
5.01E+00	9.6044E-07
3.98E+00	1.2478E-06
3.16E+00	1.6156E-06
2.51E+00	2.0466E-06
2.00E+00	2.4678E-06
1.58E+00	2.8268E-06
1.26E+00	3.0846E-06
1.00E+00	3.3186E-06
7.94E-01	3.6001E-06
6.31E-01	3.9236E-06
5.01E-01	4.1059E-06
3.98E-01	4.0612E-06
3.16E-01	4.8507E-06
2.51E-01	5.0285E-06
2.00E-01	5.0486E-06
1.58E-01	5.0297E-06

TABLE 5

BARRIER IS 1000 g/cm², 32.83% H (CONT'D)Depth in Barrier is 1000 g/cm²

<u>Energy</u> (MeV)	<u>Flux</u> (cm ² s) ⁻¹
1.26E-01	5.7276E-06
1.00E-01	6.6162E-06
7.94E-02	5.4041E-06
6.31E-02	1.1468E-05
5.01E-02	1.1164E-05
3.98E-02	1.1156E-05
3.16E-02	7.2792E-06
2.51E-02	2.2019E-05
2.00E-02	2.2527E-05
1.58E-02	2.6219E-05
1.26E-02	3.1339E-05
1.00E-02	3.7527E-05
7.94E-03	4.5199E-05
6.31E-03	5.4190E-05
5.01E-03	6.6683E-05
3.98E-03	8.4906E-05
3.16E-03	1.0641E-04
2.51E-03	1.3343E-04
2.00E-03	1.6693E-04
1.58E-03	2.1075E-04
1.26E-03	2.6373E-04
1.00E-03	3.3174E-04
7.94E-04	4.1723E-04
6.31E-04	5.2441E-04
5.01E-04	6.5986E-04
3.98E-04	8.2996E-04
3.16E-04	1.0446E-03
2.51E-04	1.3143E-03
2.00E-04	1.6485E-03
1.58E-04	2.0856E-03
1.26E-04	2.6140E-03
1.00E-04	3.2920E-03
7.94E-05	4.1439E-03
6.31E-05	5.2116E-03
5.01E-05	6.5602E-03
3.98E-05	8.2529E-03
3.16E-05	1.0388E-02

TABLE 5

BARRIER IS 1000 g/cm², 32.83% H (CONT'D)Depth in Barrier is 1000 g/cm²

<u>Energy</u> (MeV)	<u>Flux</u> (cm ² s) ⁻¹
2.51E-05	1.3068E-02
2.00E-05	1.6387E-02
1.58E-05	2.0725E-02
1.26E-05	2.5963E-02
1.00E-05	3.2676E-02
7.94E-06	4.1103E-02
6.31E-06	5.1650E-02
5.01E-06	6.4951E-02
3.98E-06	8.1618E-02
3.16E-06	1.0260E-01
2.51E-06	1.2889E-01
2.00E-06	1.6136E-01
1.58E-06	2.0369E-01
1.26E-06	2.5464E-01
1.00E-06	3.1974E-01
7.94E-07	4.0115E-01
6.31E-07	5.0259E-01
2.51E-08	2.5852E+01

TABLE 6

BARRIER IS 2000 g/cm², 32.83% HDepth in Barrier is 1000 g/cm²

<u>Energy</u> (MeV)	<u>Flux</u> (cm ² s) ⁻¹
5.01E+02	2.6112E-09
3.98E+02	9.3171E-09
3.16E+02	2.1230E-08
2.51E+02	4.8153E-08
2.00E+02	9.4294E-08
1.58E+02	1.5437E-07
1.26E+02	1.9998E-07
1.00E+02	2.4937E-07
7.94E+01	2.7278E-07
6.31E+01	2.9997E-07
5.01E+01	3.1548E-07
3.98E+01	3.4946E-07
3.16E+01	3.9376E-07
2.51E+01	4.3011E-07
2.00E+01	3.9548E-07
1.58E+01	4.4885E-07
1.26E+01	5.2534E-07
1.00E+01	6.7069E-07
7.94E+00	9.3984E-07
6.31E+00	1.3152E-06
5.01E+00	1.9022E-06
3.98E+00	2.6322E-06
3.16E+00	3.6868E-06
2.51E+00	5.0156E-06
2.00E+00	6.4705E-06
1.58E+00	7.8076E-06
1.26E+00	8.8975E-06
1.00E+00	1.0058E-05
7.94E-01	1.1397E-05
6.31E-01	1.2785E-05
5.01E-01	1.3898E-05
3.98E-01	1.4675E-05
3.16E-01	1.7509E-05
2.51E-01	1.8644E-05
2.00E-01	1.9881E-05
1.58E-01	2.1522E-05
1.26E-01	2.5429E-05
1.00E-01	2.9696E-05

TABLE 6

BARRIER IS 2000 g/cm², 32.83% H (CONT'D)Depth in Barrier is 1000 g/cm²

<u>Energy</u> (MeV)	<u>Flux</u> (cm ² s) ⁻¹
7.94E-02	2.8222E-05
6.31E-02	4.8547E-05
5.01E-02	4.5856E-05
3.98E-02	4.9904E-05
3.16E-02	4.3802E-05
2.51E-02	9.9226E-05
2.00E-02	9.2961E-05
1.58E-02	1.0849E-04
1.26E-02	1.3097E-04
1.00E-02	1.5866E-04
7.94E-03	1.9304E-04
6.31E-03	2.3455E-04
5.01E-03	2.8863E-04
3.98E-03	3.6750E-04
3.16E-03	4.6057E-04
2.51E-03	5.7753E-04
2.00E-03	7.2252E-04
1.58E-03	9.1218E-04
1.26E-03	1.1415E-03
1.00E-03	1.4359E-03
7.94E-04	1.8059E-03
6.31E-04	2.2698E-03
5.01E-04	2.8561E-03
3.98E-04	3.5923E-03
3.16E-04	4.5214E-03
2.51E-04	5.6887E-03
2.00E-04	7.1353E-03
1.58E-04	9.0273E-03
1.26E-04	1.1314E-02
1.00E-04	1.4249E-02
7.94E-05	1.7936E-02
6.31E-05	2.2558E-02
5.01E-05	2.8395E-02
3.98E-05	3.5721E-02
3.16E-05	4.4961E-02
2.51E-05	5.6563E-02
2.00E-05	7.0930E-02

TABLE 6

BARRIER IS 2000 g/cm², 32.83% H (CONT'd)Depth in Barrier is 1000 g/cm²

<u>Energy</u> (MeV)	<u>Flux</u> (cm ² s) ⁻¹
1.58E-05	8.9704E-02
1.26E-05	1.1237E-01
1.00E-05	1.4143E-01
7.94E-06	1.7791E-01
6.31E-06	2.2356E-01
5.01E-06	2.8113E-01
3.98E-06	3.5327E-01
3.16E-06	4.4408E-01
2.51E-06	5.5787E-01
2.00E-06	6.9841E-01
1.58E-06	8.8165E-01
1.26E-06	1.1022E+00
1.00E-06	1.3840E+00
7.94E-07	1.7363E+00
6.31E-07	2.1754E+00
2.51E-08	7.7373E+01

TABLE 7

BARRIER IS 2000 g/cm², 32.83% HDepth in Barrier is 2000 g/cm²

<u>Energy</u> (MeV)	<u>Flux</u> (cm ² s) ⁻¹
5.01E+02	5.0297E-14
3.98E+02	2.4793E-13
3.16E+02	6.7197E-13
2.51E+02	1.8565E-12
2.00E+02	4.1889E-12
1.58E+02	7.3472E-12
1.26E+02	9.6608E-12
1.00E+02	1.2069E-11
7.94E+01	1.2842E-11
6.31E+01	1.3505E-11
5.01E+01	1.3484E-11
3.98E+01	1.4177E-11
3.16E+01	1.5151E-11
2.51E+01	1.5661E-11
2.00E+01	1.3613E-11
1.58E+01	1.5086E-11
1.26E+01	1.6870E-11
1.00E+01	2.0500E-11
7.94E+00	2.7099E-11
6.31E+00	3.4289E-11
5.01E+00	4.7764E-11
3.98E+00	6.2080E-11
3.16E+00	8.0406E-11
2.51E+00	1.0189E-10
2.00E+00	1.2290E-10
1.58E+00	1.4080E-10
1.26E+00	1.5366E-10
1.00E+00	1.6532E-10
7.94E-01	1.7935E-10
6.31E-01	1.9547E-10
5.01E-01	2.0456E-10
3.98E-01	2.0232E-10
3.16E-01	2.4167E-10
2.51E-01	2.5053E-10
2.00E-01	2.5153E-10
1.58E-01	2.5058E-10

TABLE 7

BARRIER IS 2000 g/cm², 32.83% H (CONT'D)Depth in Barrier is 2000 g/cm²

<u>Energy</u> (MeV)	<u>Flux</u> (cm ² s) ⁻¹
1.26E-01	2.8535E-10
1.00E-01	3.2963E-10
7.94E-02	2.6923E-10
6.31E-02	5.7144E-10
5.01E-02	5.5630E-10
3.98E-02	5.5588E-10
3.16E-02	3.6268E-10
2.51E-02	1.0973E-09
2.00E-02	1.1227E-09
1.58E-02	1.3068E-09
1.26E-02	1.5620E-09
1.00E-02	1.8706E-09
7.94E-03	2.2531E-09
6.31E-03	2.7013E-09
5.01E-03	3.3241E-09
3.98E-03	4.2325E-09
3.16E-03	5.3044E-09
2.51E-03	6.6515E-09
2.00E-03	8.3214E-09
1.58E-03	1.0506E-08
1.26E-03	1.3147E-08
1.00E-03	1.6537E-08
7.94E-04	2.0799E-08
6.31E-04	2.6142E-08
5.01E-04	3.2894E-08
3.98E-04	4.1373E-08
3.16E-04	5.2075E-08
2.51E-04	6.5517E-08
2.00E-04	8.2179E-08
1.58E-04	1.0397E-07
1.26E-04	1.3031E-07
1.00E-04	1.6411E-07
7.94E-05	2.0657E-07
6.31E-05	2.5980E-07
5.01E-05	3.2702E-07
3.98E-05	4.1141E-07

TABLE 7

BARRIER IS 2000 g/cm², 32.83% H (CONT'D)Depth in Barrier is 2000 g/cm²

$\frac{\text{Energy}}{(\text{MeV})}$	$\frac{\text{Flux}}{(\text{cm}^2 \text{ s})^{-1}}$
3.16E-05	5.1782E-07
2.51E-05	6.5144E-07
2.00E-05	8.1690E-07
1.58E-05	1.0331E-06
1.26E-05	1.2942E-06
1.00E-05	1.6289E-06
7.94E-06	2.0490E-06
6.31E-06	2.5747E-06
5.01E-06	3.2378E-06
3.98E-06	4.0687E-06
3.16E-06	5.1145E-06
2.51E-06	6.4250E-06
2.00E-06	8.0437E-06
1.58E-06	1.0154E-05
1.26E-06	1.2694E-05
1.00E-06	1.5939E-05
7.94E-07	1.9997E-05
6.31E-07	2.5054E-05
2.51E-08	1.3039E-03

TABLE 8

BARRIER IS 1000 g/cm² OF FeDepth in Barrier is 500 g/cm²

$\frac{\text{Energy}}{(\text{MeV})}$	$\frac{\text{Flux}}{(\text{cm}^2 \text{ s})^{-1}}$
5.01E+02	1.6055E-06
3.98E+02	4.3788E-06
3.16E+02	8.8224E-06
2.51E+02	1.5985E-05
2.00E+02	2.5872E-05
1.58E+02	4.0437E-05
1.26E+02	5.5840E-05
1.00E+02	7.0986E-05
7.94E+01	8.3220E-05
6.31E+01	1.0184E-04
5.01E+01	1.1610E-04
3.98E+01	1.3563E-04
3.16E+01	1.5894E-04
2.51E+01	1.8549E-04
2.00E+01	1.5808E-04
1.58E+01	1.8141E-04
1.26E+01	2.4355E-04
1.00E+01	3.6064E-04
7.94E+00	5.6033E-04
6.31E+00	8.9836E-04
5.01E+00	1.4997E-03
3.98E+00	2.3872E-03
3.16E+00	3.8567E-03
2.51E+00	5.8861E-03
2.00E+00	9.7478E-03
1.58E+00	1.6942E-02
1.26E+00	2.6670E-02
1.00E+00	4.3420E-02
7.94E-01	1.6514E-01
6.31E-01	2.1624E-01
5.01E-01	4.5029E-01
3.98E-01	4.0200E-01
3.16E-01	7.0592E-01
2.51E-01	1.1573E+00
2.00E-01	1.2875E+00

TABLE 8

BARRIER IS 1000 g/cm² OF Fe (CONT'D)Depth in Barrier is 500 g/cm²

$\frac{\text{Energy}}{(\text{MeV})}$	$\frac{\text{Flux}}{(\text{cm}^2 \text{ s})^{-1}}$
1.58E-01	2.5578E+00
1.26E-01	1.7112E+00
1.00E-01	3.0791E-00
7.94E-02	2.2820E+00
6.31E-02	4.1601E+00
5.01E-02	3.6160E+00
3.98E-02	4.3859E+00
3.16E-02	3.1833E+00
2.51E-02	9.5145E-01
2.00E-02	2.5505E+01
1.58E-02	1.7405E+01
1.26E-02	1.4100E+01
1.00E-02	1.2708E-01
7.94E-03	1.0409E+01
6.31E-03	1.5501E-01
5.01E-03	2.5509E-01
3.98E-03	3.5605E-01
3.16E-03	4.1705E+01
2.51E-03	5.0606E-01
2.00E-03	5.8607E-01
1.58E-03	6.6624E-01
1.26E-03	7.4231E-01
1.00E-03	8.3252E-01
7.94E-04	9.5850E-01
6.31E-04	1.1917E+02
5.01E-04	1.3403E+02
3.98E-04	1.6256E+02
3.16E-04	1.9621E+02
2.51E-04	2.3876E+02
2.00E-04	2.8771E+02
1.58E-04	3.5587E+02
1.26E-04	4.3658E+02
1.00E-04	5.3675E+02
7.94E-05	6.5762E+02
6.31E-05	8.0236E-02
5.01E-05	9.7623E+02

TABLE 8

BARRIER IS 1000 g/cm² OF Fe (CONT'D)Depth in Barrier is 500 g/cm²

<u>Energy</u> (MeV)	<u>Flux</u> (cm ² s) ⁻¹
3.98E-05	1.1822E+03
3.16E-05	1.4260E+03
2.51E-05	1.7103E+03
2.00E-05	2.0333E+03
1.58E-05	2.4221E+03
1.26E-05	2.8383E+03
1.00E-05	3.3155E+03
7.94E-06	3.8368E+03
6.31E-06	4.3929E+03
5.01E-06	4.9794E+03
3.98E-06	5.5730E+03
3.16E-06	6.1574E+03
2.51E-06	6.7000E+03
2.00E-06	7.1505E+03
1.58E-06	7.5557E+03
1.26E-06	7.7557E+03
1.00E-06	7.8252E+03
7.94E-07	7.7042E+03
6.31E-07	7.3823E+03
2.51E-08	2.1959E+06

TABLE 9

BARRIER IS 2000 g/cm² OF FeDepth in Barrier is 2000 g/cm²

<u>Energy</u> (MeV)	<u>Flux</u> (cm ² s) ⁻¹
5.01E+02	2.9441E-12
3.98E+02	1.6594E-11
3.16E+02	4.8024E-11
2.51E+02	1.1505E-10
2.00E+02	2.2289E-10
1.58E+02	3.9365E-10
1.26E+02	5.6553E-10
1.00E+02	7.0064E-10
7.94E+01	7.8402E-10
6.31E+01	9.3673E-10
5.01E+01	1.0240E-09
3.98E+01	1.1447E-09
3.16E+01	1.2677E-09
2.51E+01	1.4116E-09
2.00E+01	1.5823E-09
1.58E+01	1.8725E-09
1.26E+01	1.5910E-09
1.00E+01	2.2182E-09
7.94E+00	3.2866E-09
6.31E+00	5.0015E-09
5.01E+00	7.9931E-09
3.98E+00	1.1975E-08
3.16E+00	1.8076E-08
2.51E+00	2.6363E-08
2.00E+00	4.1648E-08
1.58E+00	7.0132E-08
1.26E+00	1.0561E-07
1.00E+00	1.7509E-07
7.94E-01	6.7848E-07
6.31E-01	6.9159E-07
5.01E-01	1.5936E-06
3.98E-01	1.0947E-06
3.16E-01	2.0269E-06
2.51E-01	3.7095E-06
2.00E-01	3.7141E-06
1.58E-01	9.9721E-06
1.26E-01	6.6715E-06
1.00E-01	1.2004E-05
7.94E-02	8.8969E-05

TABLE 9

BARRIER IS 2000 g/cm² OF Fe (CONT'D)Depth in Barrier is 2000 g/cm²

$\frac{\text{Energy}}{(\text{MeV})}$	$\frac{\text{Flux}}{(\text{cm}^2 \text{ s})^{-1}}$
6.31E-02	1.6219E-05
5.01E-02	1.4214E-05
3.98E-02	1.7099E-05
3.16E-02	1.2411E-05
2.51E-02	3.7094E-06
2.00E-02	9.9436E-05
1.58E-02	6.7857E-05
1.26E-02	5.6139E-05
1.00E-02	5.0325E-05
7.94E-03	4.0932E-05
6.31E-03	6.0768E-05
5.01E-03	1.0124E-04
3.98E-03	1.3101E-04
3.16E-03	1.6259E-04
2.51E-03	1.9765E-04
2.00E-03	2.2849E-04
1.58E-03	2.5974E-04
1.26E-03	2.8940E-04
1.00E-03	3.2457E-04
7.94E-04	3.7368E-04
6.31E-04	4.6459E-04
5.01E-04	5.2254E-04
3.98E-04	6.3378E-04
3.16E-04	7.6508E-04
2.51E-04	9.3085E-04
2.00E-04	1.1217E-03
1.58E-04	1.3874E-03
1.26E-04	1.7021E-03
1.00E-04	2.0925E-03
7.94E-05	2.5639E-03
6.31E-05	3.1281E-03
5.01E-05	3.8060E-03
3.98E-05	4.6092E-03
3.16E-05	5.5593E-03
2.51E-05	6.6678E-03

TABLE 9

BARRIER IS 2000 g/cm² OF Fe (CONT'D)Depth in Barrier is 2000 g/cm²

<u>Energy</u> (MeV)	<u>Flux</u> (cm ² s) ⁻¹
2.00E-05	7.9270E-03
1.58E-05	9.4429E-03
1.26E-05	1.1065E-02
1.00E-05	1.2926E-02
7.94E-06	1.4959E-02
6.31E-06	1.7127E-02
5.01E-06	1.9413E-02
3.98E-06	2.1727E-02
3.16E-06	2.4006E-02
2.51E-06	2.6121E-02
2.00E-06	2.7878E-02
1.58E-06	2.9457E-02
1.26E-06	3.0237E-02
1.00E-06	3.0508E-02
7.94E-07	3.0036E-02
6.31E-07	2.8781E-02
2.51E-08	3.8670E+00